Systems Center
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INFORMATION PAPER

Design and Management Issues

Closed Circuit Television System

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Prepared by:

SPAWAR Code 743
U.S. Marine Corps Electronic Security Systems
Larry Barfield ***(Project Engineer)***
Jerry Suggs ***(Project Engineer)***

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1.0 INTRODUCTION

Closed Circuit Television (CCTV) Systems are used today in ever widening roles in law enforcement and security. These roles can be broadly categorized as (a) detection, (b) area surveillance, and (c) post incident assessment and analysis. Furthermore, the equipment used to fulfill these roles is expected to remain functional over a wide range of environmental and man-made conditions. CCTV Systems are expected to deliver unfettered quality video in lighting conditions ranging between sunlight to starlight, high contrast ratios (light to dark), and other adverse conditions. While technological advances have solved many of these issues, proper design and application are still major factors in achieving quality video assessment systems, and thusly end-user satisfaction.

No matter how much attention is given to requirements, the environment, or the technical techniques used, a CCTV project will invariably fail if Human Factors are not considered in processing the received and displayed data. Studies have concluded that the attention span of human operators can be as short as 30 minutes and events can go completely unnoticed due to the mesmerizing effects of staring at a fixed scene. Merely selecting quality and expensive hardware does not guarantee the success of a CCTV Project; strict adherence to system engineering principles, full knowledge of the environment, and an understanding of the human factors must be prevalent in the planning, design, and installation of every CCTV System Project.

1.1 BACKGROUND

The horrific events of 11 September 2001 has shown security managers the need to improve security in areas previously not considered to be threatened. Many mangers have tried to solve their information needs by purchasing CCTV systems and components. The idea for this paper was prompted by this proliferation of systems and components with seemingly little regard for the natural environment, operational settings, operator workload, and adherence to systems engineering principles.

1.2 PURPOSE

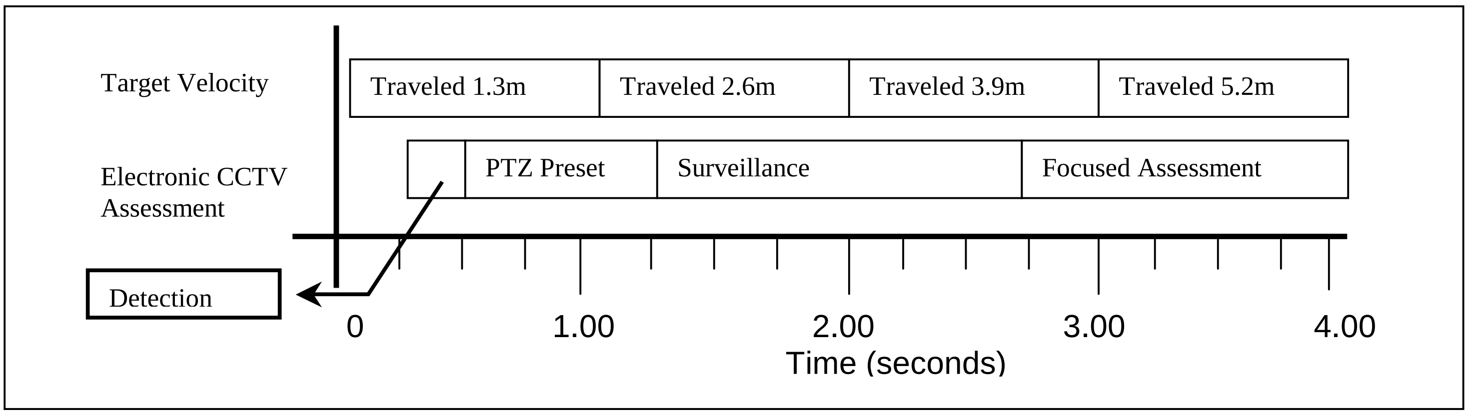
This paper discusses the aforementioned issues and presents concepts and tools for effectively designing, installing and operating a CCTV system. The discussion is broken down into three major areas of concern, (a) environmental issues, (b) technical issues, and (c) human factors.

2.0 DISCUSSION

2.1 GENERAL

The role of Closed Circuit Television Systems has expanded greatly since the 1970's. Their first widespread military application was fixed scene surveillance in conjunction with intrusion detection sensors. This development was closely followed by event-driven surveillance whereby intrusion detection sensors triggered a switching matrix to present an operator with a view of the sensor's zone. These installations were usually designed to provide video coverage within a narrow, pre-defined Field Of View (FOV) with little concern for viewing activity outside the immediate axis of concern (e.g., the area between 2 parallel fences). As a result, awareness of a potential threat outside the Camera's FOV went unnoticed until the first line of defense had already been penetrated.

This early design deficiency was addressed with the introduction of



articulated camera platforms and advances in video switching techniques. Pan tilt, zoom (PTZ) cameras allowed operators to view areas with a 359 degrees arc of the camera's position. Large zoom lenses (up to 350mm focal lengths) provided discernible images of crawling human targets at ranges exceeding 750 meters. Video switches allowed sensor signals to override operator manipulations and pan tilt and zoom to pre-selected scenes. While this technology provided near real-time assessment of alarm signal causes, it was often initiated too late to capture the actual alarm cause (except at the low end of detectable velocity). The illustration above compares system response to intruder velocity.

Attempts were then made to begin the assessment process prior to an actual alarm signal, often called "pre-alarm assessment. These attempts relied heavily of video recording equipment that stored scenes on a thirty seconds continuous loop. However, video storage was limited at that time to magnetic tape (VHS formats). Time lapse recording became popular, but large-scale projects (10 or more camera) produced an overwhelming amount of data that was not easily re-captured nor displayed with sufficient speed to allow for anything other than post-incident analysis.

Recording technologies found a place in Physical Security. In situations where video could be used to identify, apprehend, and prosecute offenders, video recording provided a technological leap. However, as a real-time assessment tool, it proved to be of little value.

Advances in digital capture, transmission, processing, storage and display have addressed, and in many cases solved, the shortcomings of these early systems. Computers collect, tag, and store thousands of images per minute, and can recall a series of images in real time for review. Additionally, digital images can easily be enhanced to compensate for poor lighting contrast or color. Digital enlargement is also more easily accomplished to the extent that camera and lens resolution allow. Digital capture systems also allow chain-of-custody authentication in situations where the video may be introduced and be required to stand up as evidence in a court of law.

These CCTV technological advances have presented new opportunities and challenges to system designers and security managers. Mainly, the question to be answered is how to display the tera-bytes of video data to operators in a meaningful cohesive manner that truly enhances security without unduly increasing the operator(s) workload.

2.2 ENVIRONMENTAL ISSUES

Since cameras operate much like a human eye, factors that affect our ability to see clearly also affect camera's ability to see clearly. Rain, fog, snow, ice, sleet, sunlight, darkness, scene contrast smog, and haze all affect a camera's ability to capture useful images. Our eyes, however, have one major advantage; they are attached to our brain that provides the high level processing. When designing and using CCTV, one can only recognize that performance will be degraded during periods of inclement weather. There are some common sense issues that should be considered in every CCTV project. Proper equipment selection and design will mitigate many of these effects and ensure cameras function over the widest range of conditions.

When faced with adverse weather conditions (hi/low temperatures, humidity, ice, snow and sleet) it is prudent to ensure that cameras are equipped with environmentally sealed housings, include internal heaters, and are positively pressurized with an inert drying agent (Nitrogen is the most commonly used agent). While these features add cost to the camera, they will help to assure uniform performance over the widest range of conditions.

There are many issues associated with lighting that must be considered during the planning and design phases of CCTV projects. Since a camera's iris automatically adjusts to ambient light conditions (just as our eyes do), planners and designers should avoid placements that are along the path of the sun and moon. Bright objects will cause the iris to narrow and thus reduce the amount of light allowed to reach the camera's sensing element. In other words, dark places will appear darker and scene visibility can be reduced to zero. However elementary the above commentary seems to be, the same principles hold true for man made illumination and should be given the same consideration. Street lights, flood lighting, and headlights within the camera's FOV will affect overall performance and should be avoided.

Areas with high contrast ratios should also be avoided. Ratios of greater than six to one (6:1) can make viewing the darker areas extremely difficult as the lens' iris will adjust to the lighter area. Natural areas of contrast should be avoided. Man made areas can be mitigated with supplemental lighting. The selection of supplemental lighting should take into account the sensitivity of the camera to the light spectrum. Most monochrome cameras have a high response across the visible light spectrum and tend to peak in the orange to near infrared range. Color cameras have similar response curves though some colors may be lost as available lighting approaches the near infrared range. When selecting supplemental lighting, decisions should be based on the requirement or desired result, and the specific response sensitivity characteristics of the camera.

2.2 TECHNOLOGY ISSUES

General

The two types of video systems are considered below; (a) analog systems, and (b) digital systems. Each type has advantages and limitations. While detection, surveillance and post-action assessment requirements vary among users, all requirements have common features and a limited number of equipment solutions. When determining the type of technology to include in a system design, designers and managers should carefully examine not only those camera qualities that meet their requirements, but also have a full understanding of their associated limitations. Video display and storage technologies are also addressed.

Analog systems are typically hardware dependent. That is, they display images on a television-like monitor, record the data to videotape, and with the aid of specifically designed printers, can produce paper images. Storing and retrieving these types of data in an efficient manner has been a most difficult challenge. Analog technology is extremely dependent on the application environment. Scene lighting is critical to producing quality images. For applications involving after-action analysis, these types of systems offer a relatively low-cost, high performance solution when used in small quantities. When applied to larger installations, the infrastructure costs can rise exponentially. This is due to the wiring requirements (one camera requiring a coaxial cable or fiber back to a central monitoring center).

Digital systems are software dependent. Not only can digital images be displayed, recorded, or printed on an array of widely used media, digital images take only seconds to search, focus on a specific scene, resize, crop, enhance quality, and e-mail. The major benefit to digitized video is the ability to store large amounts of digitized images and improving the ability to search and retrieve images quickly. Infrastructure costs are also lower since digital video images can be networked.

Cameras

Every camera consists of four basic components – the lens, a view finder system, an image sensor and a processing system. The majority of all cameras combine all four components in one casing. The lens plays a central role in cameras. Due to the difference in size between the sensor of a camera, optical components for digital cameras have to be better than for an analog camera. A variety of lenses are available to meet the changing needs of the user. Lenses are selected based on the resolution requirements and the distance from the camera's position and the object(s) to be viewed. It is also important to remember color camera cameras usually offer lower resolution than black & white cameras.

Forward Looking Infrared (FLIR) cameras essentially measure the radiated temperature of animate and inanimate objects within their field of view. These measurements are processed to present useful video images to operators. Scene lighting has no effect on these devices as they measure heat in the infrared range. FLIR technology can provide useful images in the total absence of ambient light. This technology has relatively high procurement and maintenance costs, therefore cost-benefit analysis tools should be applied before these devices are procured and deployed.

FLIR cameras can be categorized into two areas; cryocooled and uncooled. Cooled cameras (short-wave) offer longer range, higher resolution and better adverse weather penetration. These features are offset by two considerations; a) procurement costs that are typically five to ten times the cost of uncooled FLIR cameras and b) a typical cooler life span of 8,000 – 10,000 hours. Cryocooler refurbishment typically costs $8,000 – 12,000 and can be required as frequently as every 18 months. Uncooled cameras (medium-wave) typically have shorter range capabilities and lower resolution than cooled cameras. However, recent advances in infrared detector manufacturing and lens technology has resulted in uncooled thermal images rivaling those of cooled cameras and are proving effective for surveillance applications at distances up to 3,000 meters. Uncooled FLIR's do not have the maintenance costs associated with cooled cameras.

Transmission Methods

There are two types of connectivity used with video systems. The first is point-to-point and the second is networking. Point-to-point connectivity is simply a transmission media (fiber, copper, wireless, etc.) from a camera to a monitor or video switch matrix. Networking allows the video from many cameras to be multiplexed onto a single transmission media.

Point-to-point connectivity offers the highest quality video available. That is to say, coaxial cable and fiber optics offer high bandwidth and low loss over long distances resulting is high resolution and frame refresh rates. It also is the most expensive connectivity method. Video systems that utilize balanced twisted copper pairs (telephone lines) are available, but bandwidth and frame refresh rates are significantly lower and these systems are unable to meet most near real time surveillance requirements. As bandwidth and refresh rates decrease the apparent video quality diminishes, significantly for monochrome and dramatically for color.

Network connectivity allows many cameras to be physically connected to a single transmission medium and uses computer routers to allow the operator or other software to select which camera will be viewed on a monitor using Internet Protocol (IP) addressing schemes. The advantage here is that infrastructure costs are greatly reduced since a single cable is simply run from the monitoring point to the first camera then on to the next and so on and so on. Typical Local Area Networks are sometimes used to further reduce costs. However, since the video from each camera is present on the network at all times, bandwidth availability is a serious consideration. The human eye perceives as seamless video at or above a 30 frame per second. Bandwidth utilization is usually maximized by reducing the frame refresh rate to a point that the human eye perceives the viewed images as jerking or delayed (usually to about 15 frames per second). This is a function of system design and the quality of the network equipment. Managers need to be aware that there is a trade-off to be made when selecting the type of transmission media to be used in a project and that the requirement needs to be critically analyzed to ensure satisfaction.

Monitors

Two factors, size and resolution, play a significant role in choosing video monitors. The diagonal length of its viewing surface usually catalogues a monitor’s size. Typical sizes range from nine inches to twenty-one inches. One must remember that selecting a monitor should be based on the actual size and clarity one expects to view. Since monitors have the same aspect ratio as a camera (4:3), but are rated by a diagonal measurement, confusion can occur. A 20-inch monitor, for example, will display a scene 16 inches wide by 12 inches high. In reality, this translates to a 6 foot high man being represented as 2.4 inches on a 20" monitor when viewed at a distance of 20 feet from a camera that has a field of view of 30' by 40'. As this example shows, the problem becomes more exaggerated the farther the target is from the camera.

In the context of video display, resolution can be referred to either as the total number of horizontal lines (analog) or the number of pixels per inch (digital). In either case, it determines the amount of detail that can be resolved. A common mistake is failing to match the specified camera resolution with a display device of equal or higher resolution, which results in image distortion. The importance of resolution cannot be overstressed. No penalty is exacted by a display with resolution exceeding that of the camera. Flat screen monitors such as LCD and plasma convert analog signals to digital, which means slower speeds than the conventional CRT monitor. Attention must be given to the global aspects of the video system in order to produce a well-engineered, optimized display resolution for the operator. As one would expect, the higher the resolution specified the higher the equipment costs.

2.3 HUMAN ENGINEERING ISSUES

The discussion above has focused on the environmental and technical factors governing system selection and design. However, even the most effectively designed system will be of marginal use if the human operators are not made a part of the design and implementation equation. The specific areas of operator proficiency requiring managerial and deign personnel attention include:

Task Organization
Task Management
Social Issues
Technology

Each of these is discussed below as well as some ideas managers and designers may choose to incorporate in their system and concept of operation. In the course of this discussion, articles written by Dr. Donald Craig, Hi-Tech Security Systems, SA have been heavily relied upon.

Prior to the beginning of the design process, security managers contemplating the use of CCTV should evaluate the intended outcome. Three categories broadly describe typical CCTV use: (a) Detection, (b) Surveillance, (c) After Action Assessment. CCTV detection is the action of catching a desired activity in real-time such as an intrusion into a restricted area. Surveillance is the action of monitoring a given area for undesired activity, such as acts of vandalism, sabotage, unauthorized entry, etc. After Action Assessment is the after-the-fact analysis of video data to determine sequences of events that lead to, or occurred, during a specific timeframe. Each of these categories should require different actions by systems operators. Further, each camera should be assigned to one of the above categories. This separation of function allows managers to define the actions and responsibilities of not only the operators, but also the roles and responsibilities of security managers/supervisors.

Detection Cameras.

If the purpose of a specific camera is to detect undesired activity in a given area, video data need only be presented to an operator when the undesired activity is present. Since the majority of these types of activities are related to motion, there are several technologies and matrix applications that can rapidly draw an operator's attention to the scene. Video motion detectors and event-driven switching matrices are the key technologies in this approach. The important factor is that the information is not presented to an operator until his attention is required. It's just as important to select scenes that are benign. Normal activity in an area that triggers a sensor or otherwise prompts an operator's attention will result in information overload, and thus will tend to be ignored. Monitors displaying this type of data should be located within the peripheral vision of the operator and easily accessible once his/her attention has been captured. A more detailed discussion of control room layouts can be found below. Since many cameras may be assigned to this category, but only used when an event occurs, operator fatigue is not as critical a factor. Designers should pay strict attention to factors affecting false alarm rates so as not to overload an operator with meaningless data. Also, since these types of events are occurring in real-time, operators should be fully familiar with detection areas. They should have pre-planned procedures of follow-up actions and, if the camera is mounted on an articulating platform (PTZ), possess the knowledge and manual dexterity to rapid manipulate the camera's view as the situation may require.

Surveillance Cameras.

If the purpose of a camera is to provide surveillance of a specified area, the workload on the operator is significantly increased. Therefore, the amount of video data being presented to an operator must be considered. If many cameras are assigned this role, then monitoring options include adding additional personnel to monitoring assignments and using technology to "scroll" through the various cameras in a pre-determined order and rate. To determine the number of cameras assigned to each monitor, the time each camera's scene will be displayed (dwell time) becomes critical. Consider a monitor having 20 cameras assigned to it, each camera's scene having a dwell time of 3 seconds. That means that it will take 60 seconds before each camera is again presented to the operator. Common dwell times are between 1 and 3 seconds. With each subsequent switch to a new camera, the operator must orient himself to the new scene and then determine if there have been changes from the last time the scene was presented.

Using multiple monitors may alleviate some of this problem, but it introduces others. If multiple monitors are assigned to this duty, then a single operator is required to split his/her attention between these various monitors. Couple this with the factor that each monitor is presenting different scenes every one to three seconds and it becomes clear that information can be easily missed. This activity can be mentally fatiguing as well. Therefore the amount of time an operator remains in this mode becomes critical. Research has shown that an operator's performance is dependent on his/her personality type. But even if mentally suited for CCTV surveillance tasks, performance begins to degrade after approximately 30 minutes. After that, though not linear nor true for every individual, the likelihood of an undesired event being seen can diminish to as little as 50% of the time.

Security managers should be aware of these limitations and carefully ascertain the need for these types of cameras. If the need is present, then managers should limit their number to that which is commensurate with the amount and type of manpower available for the task.

After-Action Assessment Cameras.

This category is actually the easiest of the three to deal with. Mostly, because it requires little or no attention from the operator. Cameras assigned to this category most often have their output directed to a video storage unit. The challenge is to select video storage equipment capable of quickly retrieving useful information. The discussion in the technology issues section of this document has addressed several of these issues.

Security managers must also evaluate other tasks assigned to the CCTV system operator. CCTV operation can be a task unto itself, but there are few cases in the military police environment where personnel can be so dedicated to a single task. Therefore, the manager must also consider other duties assigned to an operator. Such things as monitoring an Electronic Security System (ESS), Mass Notification System (MNS), answering telephone inquiries, and interaction between the operator and other personnel in the area must all be considered to effect a high performance CCTV system.

Other influences on operator proficiency must also be considered. The number of personnel within a control room or station and the social interaction of these personnel can distract or otherwise command the attention of an operator, and these influences can reduce the effectiveness of a surveillance system. Managers can design and implement policies and procedures to increase proficiency, but the human nature dictates these factors will exist and must be considered in the design phase.

Control room layout is just as important to effective use of CCTV systems. Monitors and controls should be placed with respect to an operator such that it is not a burden or strain on the operator. Monitors should be sized to reduce eyestrain. Viewing angles should be within the natural limits of eye and neck movement. Controls should be intuitive to an operator and not require complicated actions to bring an image to his/her attention. No more than 3 keystrokes should be required to bring any camera to any monitor to any operator. Pan, tilt, zoom controls should also require no special dexterity for viewing areas of significance and should be incorporated into a single control unit. Control room lighting should be selected to reduce glare. Typical console or control station designs should adhere to the human engineering principles outlined in the Human Engineering Guide to Equipment Design.

Lastly, to be effective, operators must be familiar with the areas they are being asked to view. Managers should establish initial and on-going training programs to ensure that operators are familiar with the system design, principle landmarks, and/or special circumstances (e.g., construction projects). Operators should be aware of distances between the camera location and significant points within its field of view. Operators lose depth perception when viewing camera scenes and can experience difficulty in relaying accurate information to other personnel dispatched to investigate.

3.0 SUMMARY

Effective use of closed circuit television technology can increase the level of security over a wide area and can increase the effectiveness of available manpower (force multiplication). This paper has attempted to outline the many considerations that require attention for managers and designers before implementing these systems. Environmental, technological and human factors all play equally important roles in determining effective use of cameras and associated equipment.

Determining the requirements and expectations of a video system will lead to successfully procuring and implementing this technology. Managers should determine what needs to be seen and to what level of detail. Environmental conditions must be determined and how changes in these conditions will affect a system's performance over time.

Finally, these requirements as well as any operational and aesthetic restrictions should be communicated to a professional engineer trained in selecting and deploying video equipment. Simply assuming that CCTV will enhance security without due vigilance to the factors discussed here will lead to less than optimized performance and user dissatisfaction.